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TUNING THE FILTERS OF 18-CHANNEL TONAL-TELEGRAPHY EQUIPMENT

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A short description of filters and the requirements they must meet is given, a procedure for testing and tuning band filters under operating conditions is described, and circuits are given for filter tuning setups.

To separate the telegraph channels in 18-channel "tonal'noye telegrafirovaniye" [tonal-telegraphy] (TT) apparatus with amplitude modulation, one employs 2 groups of band filters of the differential-bridge type: one group for the transmission direction (transmission filters) and the other for the reception direction (reception filters).

The group of transmission filters consists of one line differential transmission transformer LT_1 which is common for the transmission direction, and 3 networks for each channel, tuned with allowances for the inductance of the transformer windings under matched load at the input and output of the filters. Figure 1 shows the diagram of the transmission filter of one of the channels. The network L_3C_3 is tuned to resonance at the fundamental frequency f_0, which equals the frequency of the carrier current of the given channel, while networks L_1C_1 and L_2C_2 are tuned to f_0 - 50 cycles and f_0 + 50 cycles respectively. The characteristic impedances of the transmitting filters on the input sides are rated 200 ohms at the fundamental frequency; their impedances on the output sides are 600 ohms.

The reception filter group contains one line differential reception transformer LT_2 common for the reception direction, and 4 networks for each channel, which are also tuned with allowance for the inductances of the transformer windings under matched load on the input and output sides. The diagram of one of the reception filters is shown in Figure 2. Networks L_1C_1 and L_4C_4 are tuned to resonance at frequencies f_0 + 40 cycles and f_0 - 40 cycles respectively, while networks L_2C_2 and L_3C_3 are tuned to frequencies f_0 - 20 cycles and f_0 + 20 cycles respectively. The characteristic impedance of the reception filters on the input side is 600 ohms and the characteristic impedances on the output side are 150 ohms.

In the transmission filter the resonant frequency in the L_3C_3 network equals the resonant frequency of the two-terminal network formed by the networks L_1C_1 and L_2C_2 . In the reception filter the voltage resonant frequency of the L_3C_3 network equals the current resonant frequency of the two-terminal network L_1C_1 and L_2C_2; the voltage resonant frequency of the L_2C_2 network equals the current resonant frequency of the two-terminal network L_3C_3 and L_4C_4 .

The reason the pass band of the filters is limited by the extreme frequency values f_1 and f_2 is explained physically by the fact that the reactive impedances of the two-terminal networks connected in the half-winding of the differential transformer have opposite signs in the frequency band

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from f_1 to f_2. Therefore the currents flow through the two-terminal networks and the half-windings of the transformers in opposite directions and consequently the half-winding acts in a matched manner on the total secondary winding of the transformer. On the other hand, if the frequency is lower than f_1 or higher than f_2, the reactive impedances of the two-terminal networks have the same signs; consequently, the current also flows through the half-windings of the transformer in the same direction, thereby cancelling mutually the action of the half-windings of the transformer on its secondary winding. Thus, in the former case (when the reactances of the network have opposing signs) the filter has a pass band, and in the second case (when the signs are equal) it has a rejection band. The limiting frequencies that limit the frequency passband are the extreme resonant frequencies; the width of the pass band for the transmission and reception filters is therefore amounted to 100 and 80 cycles respectively. The attenuation frequency characteristic of the reception pass filters must meet more rigid requirements than the characteristics of the transmission filters. Better characteristics are obtained by employing a larger number of networks in the reception filter circuit and by suitably choosing their parameters.

In the narrow-band filters of the TT apparatus even an insignificant deviation of the parameter of any network element from its nominal value leads to a considerable change in the filter characteristics. Experimental operation of the 18-channel TT apparatus shows that under the influence of the humidity or temperature of the building in which the equipment was stored or operated, the most likely to deviate from their nominal values are the capacitors of the filters. This is why the tuning of the filters under operating conditions of the TT apparatus usually reduces to checking the capacitance of the network capacitors, detection and replacement of faulty capacitors, or bringing the capacitance of these capacitors to the nominal value by adding parallel trimming capacitors.

One of the principal requirements to be met with regard to the filters of the TT apparatus is that the filter attenuation must be kept within the permissible variation limits in the pass band. The attenuation varies in this band because of losses in the filter and depends principally on the Q factor of the network elements. In order to improve the frequency characteristic of the filter it is recommended that not more than one or 2 trimming capacitors be connected in parallel with the principal capacitor, since connecting individual capacitors in parallel reduces the overall Q of the capacitance of the circuit and increases the nonuniformity of filter attenuation.

To determine the permissible deviations in the filter attenuation over the entire pass band from the attenuation at the fundamental frequency the following equations, verified in practice, are recommended.

For the transmission filter:

$$\Delta b = 0.00017 \, \Delta f^2 \text{ nep}$$

and for the reception filter:

$$\Delta b = 0.00025 \, \Delta f^2 \text{ nep},$$

where Δf is the difference between the carrier and given frequencies in cycles, and Δb is the maximum permissible increase in attenuation at a given frequency relative to the attenuation at the carrier frequency.

Figures 3 and 4 show the frequency dependence of the maximum permissible attenuation, calculated according to the equations given (curves b_{max})

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for the transmission and reception filters respectively. The curves b_{min} characterize the frequency dependence of the filter attenuation for the case when the attenuation is ideally uniform over the entire pass band frequencies.

Depending on the number of the channel, the maximum permissible attenuation of the transmission filter at the fundamental frequency b_f is determined approximately from the following equation:

$$b_f = 0.01n + 0.26 \text{ nep}$$

where n is the number of the channel.

The same value of b_f for the reception filters of the first to the sixteenth channels is

$$b_f = 0.02n + 0.38 \text{ nep}$$

while the value of b_f for the seventeenth and eighteenth channels is 0.76 and 0.8 nep respectively.

To plot the frequency characteristics of filter attenuation and to check the agreement of the resonant frequencies of the individual networks it is essential to regulate accurately the frequencies supplied by the measuring generator to the input of the measured filters. At the present time the system of TT channels contains but a small number of measuring generators and frequency meters, and the scales of these instruments do not allow sufficient accuracy in setting the frequency. Under practical conditions, in the absence of precision frequency meters of the laboratory type, it is necessary to employ the method of comparing the machine and measuring generator frequencies by means of a cathode-ray oscillograph in order to select the precise frequency applied to the filter input. If the frequency of the measuring generator is applied to the vertical plates of the oscillograph, and the carrier frequency of the channel of the filter to be tuned, received from the machine generator, is applied to the horizontal plates, it is possible to produce an adequate coincidence of the frequencies of the measuring and carrier-frequency generators. Essentially this method of frequency comparison consists in obtaining on the oscillograph screen a so-called Lissajous figure; this will have the form of a closed curve which becomes stationary when the voltages applied to the horizontal and vertical plates of the cathode ray tube are equal.

Instead of using a cathode-ray oscillograph, the frequencies of the measuring generator and the machine generator can be compared by determining the zero beats, using a level indicator or a vacuum tube voltmeter VTVM as a beat indicator (Figure 5). In practice one can assume that, if the resulting beat frequency corresponds to one half cycle per second, the frequency of the measuring generator is adjusted with sufficient accuracy.

To obtain frequencies that are shifted to one side or another relative to the fundamental frequency, the scale indicator is shifted by the required number of divisions to the left or to the right from the position obtained for the value of the fundamental frequency as given by the measurement generator. In this method the error in selecting the frequency of the measurement generator, is determined by the possible deviation of the carrier frequencies of the machine generator itself from the nominal values of these frequencies. If the indicator pointer of the machine-generator frequency meter deviates within the permissible limits, the deviations of the actual carrier frequencies from the nominal values do not exceed ±0.2%. This error is not important in the tuning of the filters. Furthermore, the value of

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The accuracy with which the frequency-meter tuned network is tuned is checked with a low-frequency quartz oscillator, the circuit and design of which were described in detail in the special technical literature (A. F. Plonskiy, Piezokvarts v tekhnike svyazi [Piezoquartz in Communication Engineering] 1951, Moscow-Leningrad, Gosenergoizdat). If a photo-telegraph apparatus is contained in the telegraph station, one can use for this purpose a 1,560 cycle tuning fork. In this case the neon lamp, which illuminates the stroboscopic disk of the machine generator, is connected in parallel with the neon lamp that is contained in the stroboscopic device of the phototelegraph apparatus. Serving as the stroboscopic disk on the machine generator is the cover of the regulator, whose periphery is first covered with 52 black and 52 white strips. The stroboscopic effect, i.e., the stationary position of the strips on the disk illuminated by a neon bulb at 1,560 cycles (the frequency of the tuning fork of the phototelegraphic apparatus) occurs when the armature of the machine generator rotates at 3,600 rpm. In fact 3,120 black and white strips pass through any stationary point near the periphery of the disk per second when the generator speed is of this value. Since the bulb lights up 3,120 times per second, the strips will appear stationary.

If the check just described shows that the tuned circuit of the frequency meter is out of tune (the frequency as measured by the frequency meter does not agree with the speed obtained by checking with the tuning fork) it is necessary to change the capacity of the capacitor of the frequency-meter tuned circuit until the machine generator speed, as determined by both methods (frequency-meter and stroboscopically) is the same.

Whenever the principal and trimming capacitors are replaced in the networks of the band filters, serious attention must be paid to their quality. The latter depends fundamentally on the insulation resistance between the electrodes, which should not be less than 500 megohms. The best replacement capacitors for tuning the filters are mica and ceramic ones.

A vacuum tube voltmeter (regularly used for the TT apparatus) can be employed as a voltage-resonance indicator for the network that is being tuned, and also as an instrument for measuring voltages whenever the frequency characteristic of the filter is plotted.

The circuit used to hook up the instruments for tuning the transmission filter is given in Figure 6. In this drawing: MG = measurement generator, O = oscillograph, MMG = machine generator, VD = voltage divider, VTVM = vacuum tube voltmeter. Auxiliary resistors R of approximately 100 ohms are connected in the filter networks on the side of capacitors C_1 -- C_3. Using switch S it is possible to connect the vacuum tube voltmeter VTVM to the input and output of the filter and also to the auxiliary resistors. The measurement generator is connected to the input of the filter through the voltage divider. Provision is also made for simultaneously connecting to the output of the measurement generator, say, the horizontal deflection plate of the oscillograph, while the machine generator is connected to the vertical plates. The output of the filter networks on the side of inductances L_1 -- L_3 is connected to an auxiliary differential line transformer LT, loaded on its secondary side by a resistance of 600 ohms. If the voltage divider VD has a high output resistance, the load (150 ohms) is connected in parallel to the input. On the other hand, if a low-resistance voltage divider is used, the load is connectod in series with the input of the filter.

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The filters are tuned and checked in the following sequence.

(1) Check insulation of filter capacitors.

(2) Set the nominal resonant frequencies of the filter networks by changing the capacitances of the tuning capacitors.

(3) Plot the frequency characteristic of the filter attenuation.

For example, to tune the transmission filter of the first channel, the frequency of the measurement generator is set at 420 cycles and is compared with the frequency of the machine generator of the first channel. For this purpose the voltage from the machine generator of the first channel is applied to the vertical plates of the oscillograph, while the voltage from the measurement generator is applied to the horizontal plates. In that case the frequency of the measurement generator will be 420 cycles when the indicator of the generator scale will occupy a position at which the image of the closed curve on the oscillograph screen becomes stationary.

Using the voltage divider connected at the input of the measurement circuit, the voltage of the applied measurement frequency is set at 90 mv. Such limiting of the voltage used for tuning the filter networks is necessary to prevent saturation of the inductance-coil cores, which can affect the accuracy and sharpness of the resonant tuning. To measure the voltage applied to the input of the measuring circuit, the vacuum tube voltmeter VTVM is connected by switch S to points 1 -- 3. To check the network L_1C_1 the voltmeter is connected to points 3 -- 4. The resonant frequency of the network is obtained by shifting the scale indicator of the measurement generator to a position at which the voltage drop across the auxiliary resistor R of the L_1C_1 network is a maximum (approximately 15 mv). The resonant frequency so obtained is determined on the scale of the measurement generator by the value of the shift of the scale indicator from the position occupied by this indicator at 420 cycles.

The resonant frequencies of networks L_2C_2 and L_3C_3 are checked in a manner similar to that used for network L_1C_1. The difference lies in the fact that the resonant frequencies of the network are determined by switching the vacuum tube voltmeter to points 2 -- 3 and 3 -- 5 respectively, so as to measure the voltage drops across the auxiliary resistors R connected in the L_2C_2 and L_3C_3 networks.

It is quite difficult to obtain a direct and accurate reading of the resonant frequency of the filters of the tenth to the eighteenth channels by using the maximum indication of the vacuum tube voltmeter. Therefore, bearing in mind that the resonance curve can be assumed symmetrical for all practical purposes, the resonant frequency is taken to be the arithmetic average of the 2 frequencies lying below and above the resonant one (near the resonant one), for which the readings of the voltmeter are identical.

The resonant frequency of the L_1C_1 network should be within f_0 - (50 to 55) cycles, and that of the L_2C_2 network should be within f_0 + (50 to 55) cycles, where f_0 is the carrier frequency of the channel of the measured filter. If the resonant frequency of the network being tuned is within the required limits, no changes whatever should be made to the network. If the resonant frequency of the network is less than the required value, the capacitance of the tuning capacitors of the network is decreased, and if it is greater, this capacitance is increased. It is necessary to see to it that the absolute value of the resonant frequency of the network not be less than the nominal shift of the resonant frequencies relative to the carrier frequency provided for the given network.

To plot the frequency characteristic of the filter attenuation within a frequency band of ± 120 cycles from the fundamental frequency of the given channel, the key K is used to shunt the auxiliary resistances R of the networks. The vacuum tube voltmeter is first connected to points 1 -- 3 and the voltage divider is used to establish at the input of the measurement circuit the zero level of voltage (0.775 v). Next, changing the measurement frequencies on both sides of the fundamental frequency, the readings of the vacuum tube voltmeter, which is connected to points 6 -- 7, are plotted for every 10-cycle change.

If the generator and the terminal load are matched with the input and output of the filter, as occurs when this measurement circuit is used, the attenuation b of the filter is determined as a function of one variable U_e (U at the output)

$$b = - \ln \frac{U_e}{0.775} \text{ nep.}$$

The curve of the resultant frequency dependence of the filter attenuation should lie between curves b_{max} and b_{min} (Figure 3). If there is no such agreement in the characteristic, it is necessary to change the Q factors of the inductance coil and of the capacitors of the tuned networks. Since it is quite complicated to check the Q factor under practical conditions, replacement of one filter network after another is recommended to detect the defective network.

The switching used for the reception filter networks for their individual tuning and for checking the filter as a whole is shown in Figure 7. The voltage at the input of the measurement circuit is set at 90 mv. The vacuum tube voltmeter is then connected by means of switch S to points 1 -- 2. The voltage drop across the auxiliary resistance R of network L_1C_1 (if this network is checked) is measured by connecting the vacuum tube voltmeter to points 3 -- 8. The networks L_2C_2, L_3C_3, and L_4C_4 are also checked individually at the suitable frequencies, with the instant of resonance being determined by connecting the vacuum tube voltmeter to points 3 -- 7, 3 -- 5, and 3 -- 4 respectively.

After completing the sequential tuning of all the networks it is necessary to recheck each network so as to set the capacitances of the trimming capacitors more accurately. In all other respects the procedure for tuning and checking the reception filters is analogous to the procedure for tuning and checking the transmission filters.

The premissible limits for the deviations of the shift of resonance frequencies from the nominal value for each of the networks of the reception filter are: f_0 + (40 to 45) cycles for network L_1C_1; f_0 - (20 to 25) cycles for network L_2C_2; f_0 + (20 to 25) cycles for network L_3C_3; and f_0 - (40 to 45) cycles for network L_4C_4. The resultant frequency dependence of the filter attenuation should agree with the recommended values (Figure 4).

As is known, the filters of the third rack of the channels differ from the filters of the first and second racks in that their circuits contain matching transformers, on the input side for the transmission filter and on the output side for the reception filter. In spite of this, the procedure for tuning the filters of the third rack is the same as for tuning the filters of the first to the twelfth channels. It must be born in mind that

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the networks of the filters of channel nos 13-18 must be connected to taps a and b of the line differential transformers. The tuning of the networks and the plotting of the frequency characteristics of the above filters are carried out with the matching transformers connected. The auxiliary resistors are also connected in the filter networks on the capacitor side.

For ease in manipulation during the process of measuring and tuning the filters, and also to save time in these operations, it is useful to prepare a special measurement circuit, set up in the form of a panel, on which are placed: (1) line differential transformer (reception and transmission); (2) auxiliary resistors, for the transmission and reception filters individually; (3) potentiometer for regulating the measurement voltage; (4) terminals for connecting the filters; (5) key for shunting out the auxiliary resistances; (6) transfer switch for connecting the vacuum tube voltmeter to all points of the circuit at which the voltage must be measured during the tuning of the networks and during the plotting of the frequency characteristic of the filters; (7) load resistances. The elements of the measurement panel are interconnected in accordance with the diagrams shown in Figures 6 and 7.

Using such a measurement panel it is possible to tune individual filters removed from the TT equipment. However, the measurement apparatus for tuning the filters can also be directly incorporated in the TT system (without a special measurement panel), if, for example, a spare TT system is available or if individual spare panels are available. The line reception and transmission transformers are used during the tuning of the spare-system filters, and the measurement transformer is used during the tuning of the individual-channel filters.

Let us examine the sequence with which the measurement apparatus is switched in when the line transformers are used (in principle the same sequence is used also when the measurement transformer is used). To tune the reception filters, a measurement generator with an internal resistance of 600 ohms is connected to the common reception input on the station side (terminals $kewt_1$) and a vacuum-tube voltmeter with a load of 150 ohms is connected to the output of the tuned reception filter (terminals kefv). If the transmission filters are being tuned, the measurement generator (600 ohms) is connected to the common output of the transmission on the station side (terminals $kewt_1$) and the vacuum tube voltmeter with a 150 ohm load is connected to the input of the tuned transmission filter, whereby the leads that connect the input of the filter to the modulator should be disconnected. When tuning one of the networks, the remaining networks of the filter are disconnected by removing the jumper between L and C. The voltage resonance of the networks is determined from the maximum value of the readings of the vacuum tube voltmeter. In all other respects the procedure for tuning the filters and plotting their characteristics is analogous to the procedure used when the special measurement panel is employed.

The quality of tuning the filters by directly connecting the measurement apparatus into the TT system is somewhat lower than if a special measurement panel is used. The preparation of a measurement panel is therefore fully justified if it is necessary to check a large number of filters.

To put incomplete filters in working order or to replace the elements of one of the filters by a filter of another channel it is necessary to know the inductance and capacitance of the individual networks of each of the channels. The values of the filter inductances are indicated in the table.

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Channel No	Transmission filter		Reception filter	
	L_1 and L_2	L_3	L_1 and L_4	L_2 and L_3
1-12	1.287 h	630 μh	1.657 h	780 μ h
13-18	257.5 μ h	126.1 μh	327 μh	157 μ h

The preliminary values of the capacitance for any of the filter networks (without taking into account the inductance of the differential transformer) can be calculated from the following equation:

$$C = \frac{10^{10}}{0.395\ f^2\ L}\ \text{mmf},$$

where f is the resonant frequency of the network in cycles and L the inductance of the network in henries. The nominal capacitances (marked on the capacitors) of the principal capacitors connected in the filter networks is less than the designed values by approximately 2% (this takes into account the possibility that the actual capacitance of the capacitor will deviate from the nominal one).

In the TT apparatus the main capacitor having the highest capacity is connected in the L_1C_1 network of the transmission filter of the first channel. The capacitance of this capacitor is 214,000 mmf. The main capacitor having the smallest capacitance (4,500 mmf) is used in the L_1C_1 network of the reception filter of the twelfth channel. The capacitance of the trimming capacitors in practice does not amount to more than 5% of the capacitance of the main capacitor of the network, and ranges from 0 to 12,000 mmf.

The methods described in this article were used in one of the telegraph offices to tune and check a large number of filters of the 18-channel TT apparatus. Exhaustive tests and operations of these filters have shown that their tuning is of fully satisfactory quality, and this confirms the practical suitability of the proposed method and the possibility of employing the recommended data.

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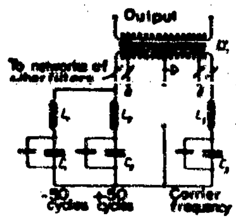

Figure 1

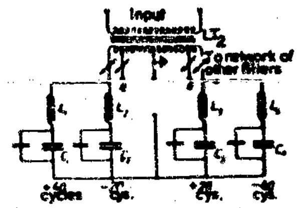

Figure 2

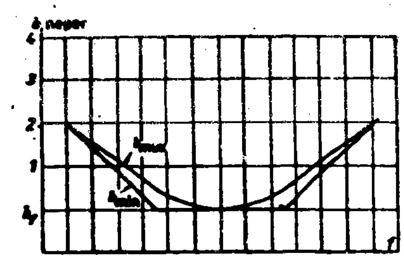

Figure 3

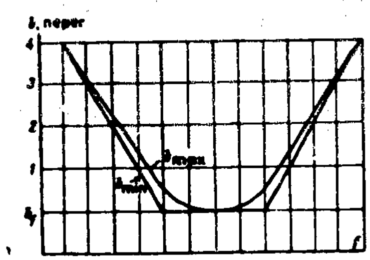

Figure 4

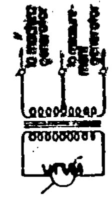

Figure 5

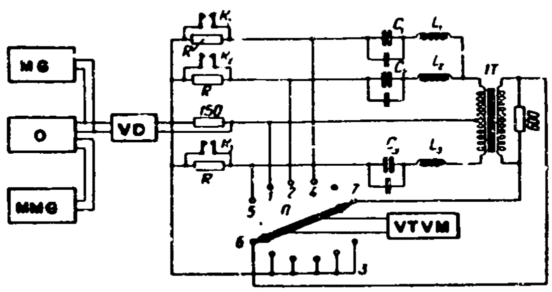

Figure 6

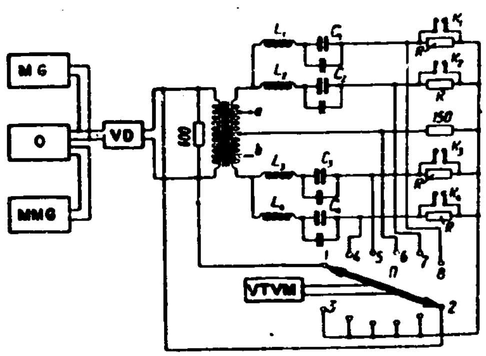

Figure 7

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